AN OPEN ENVIRONMENT FOR RAPID EMBEDDED PLANNING OF ON-THE-MOVE COMMUNICATIONS NETWORKS USING MULTI-LEVEL ABSTRACTION

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ABSTRACT

The rapid pace of future Net Centric Warfare requires that communication plans for mission specific demands be reduced from weeks/days to hours/minutes. The demands of the mobile networks change constantly as warfighters move their network infrastructure in response to battlefield dynamics, terrain, and logistics. There is a critical need for new technology to help automate the planning process for wireless on-the-move (OTM) networks. The Army's Communications Planner for Operational and Simulation Effects with Realism (COMPOSER) project is developing an open Framework with pluggable tools for assessing and planning OTM network operations that will give warfighters the ability to predict network performance required for mission success. Once on a mission, COMPOSER allows the warfighter to check plans against actual environmental and communications conditions and replan as necessary. At the heart of the COMPOSER architecture is the Communications Effects Simulator (CES), which can model dynamic OTM network, networks at multiple abstraction levels for user selectable efficiency and accuracy. This paper will describe the technical details of the COMPOSER architecture. Additional details of the COMPOSER CES, including examples of simulation abstraction techniques, will be presented. The paper also discusses the current project status and the current transition plan into ARMY operations.

INTRODUCTION AND CONCEPT OF OPERATION

COMPOSER (Figure 1) is a four year U.S. Army CERDEC Army Technology Objective (ATO) that began in September 2004. Lockheed Martin Advanced Technology Laboratories (LM ATL) is the prime contractor, with teammates Alion Science and Technology and Telcordia. COMPOSER is also coordinating with CERDEC's Applied Communications and Information Network (ACIN) Program with Drexel University as prime contractor. Composer is being developed under a spiral process, with incremental releases about every six months. The configuration management tool (CVS) and the web-based document repositories (WordPress) manage development across the team, government, and university partners. Although COMPOSER is adaptable to multiple communications programs, present and future, early transition opportunities include Warfighter's Information Network-Tactical (WIN-T).

The success of the Army's Future Force requires dependable, persistent wireless networks operating in highly dynamic physical environments. Communications requirements include battle command OTM, information dissemination, and extended reach and reach-back. The Future Force networks are multi-tiered (space, air, and terrestrial) with nodes operating within and across these tiers. The dynamic behavior and hostile environments of OTM networks makes the network planning complex. Efficient yet accurate simulation based planning is essential. COMPOSER is delivering a simulation based Communications Planner (CP) that provides pre-deployment planning and deployment re-planning needed for predicting and adapting the network configuration during the course of a mission. For pre-deployment details of the mission plan, including equipment, terrain, trajectories, required links, etc., is input into the CP. The CP quantifies and refines expected network operations, identifying hotspots, broken links, and policy violations in candidate plans during high level planning operations. The CP also generates contingency plans for configuration settings for relevant network resources, detailing the deployment of communicating nodes, the placement of network service points, QoS policies, and security assurance mechanisms. During deployment the CP receives input from real-time network monitors proactively, issuing alerts when a problem is detected, triggering planning or the actuation of an existing contingency plan.

ARCHITECTURAL AND COMPONENT DESCRIPTION

The COMPOSER CP architecture (Figure 2) is comprised of three components: Network Planner (NP), Network Visualizer (NV), and Communications Environmental Effects (CES). The NP enables the user to create, view, and edit network communications plans based on mission communications requirements. The CES simulates the behavior and characteristics of the planned network to

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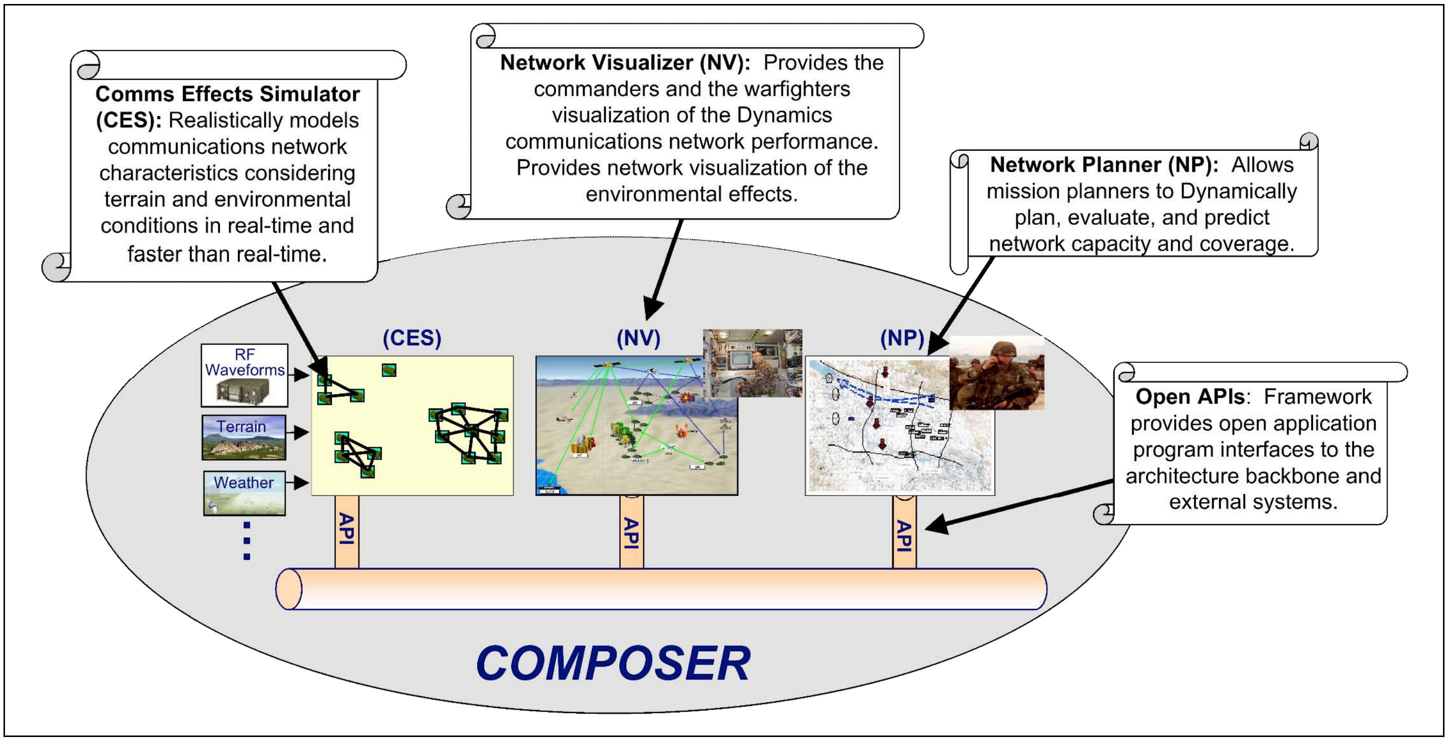

Figure 1. COMPOSER Product Overview—shows three primary components: Network Planner (NP), Communications Effects Simulator (CES), and Network Visualizer (NV) and open pluggable Framework

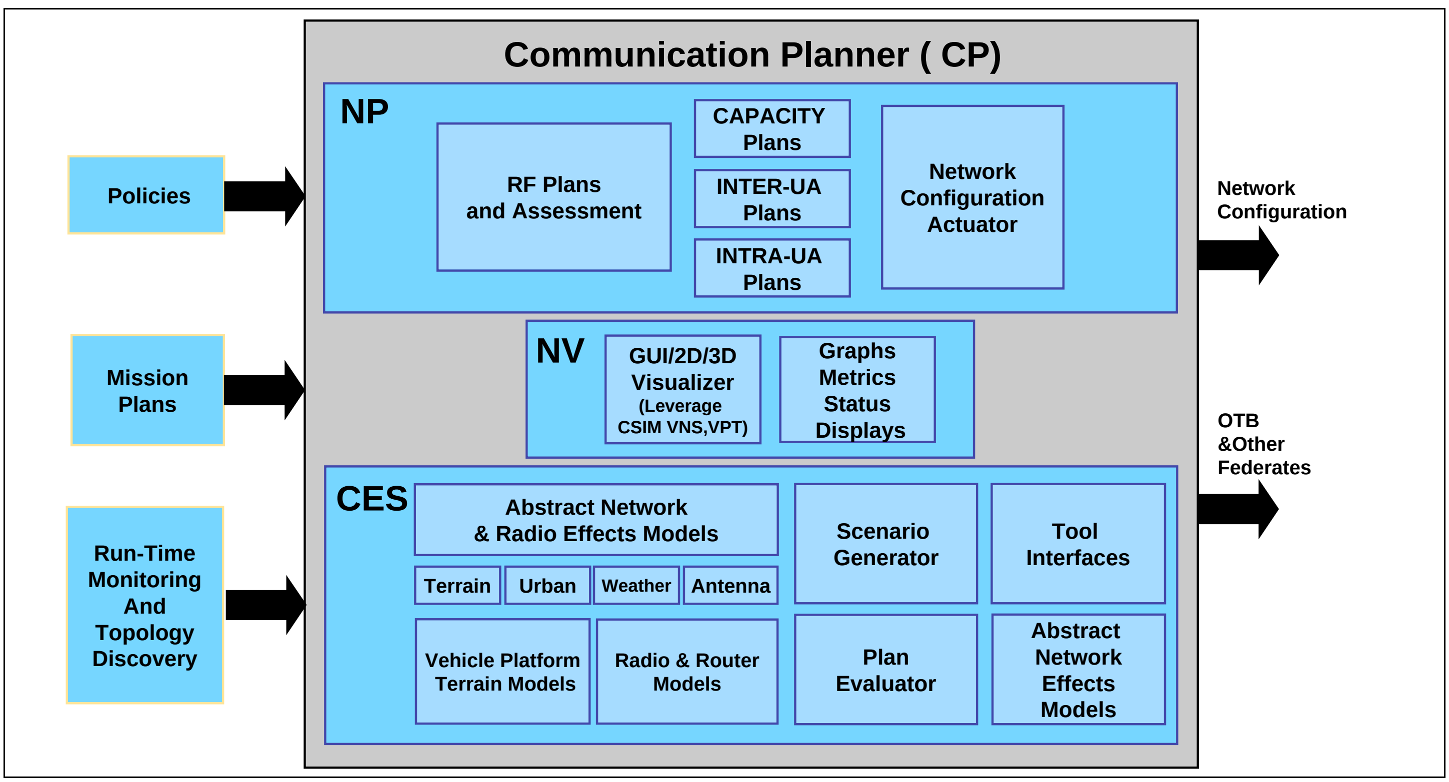

Figure 2. Detailed Architectural View Showing Internals of COMPOSER Components and Primary External Interfaces

evaluate network performance and validate network plans to meet communication requirements. The NV provides a user-friendly multi-view visualization interface that will significantly aid the planner to support the network planning and validation process.

COMPOSER's open Framework specifies an application program interface (API) for each primary component and protocols to enable the components, or alternative tools to be connected. For example, NP's associated with a specific network can replace or accompany COMPOSER's default NP. Alternative CES tools can be switched-in, especially if another possesses specific strengths for a given situation. Alternative NV tools can be added or used. COMPOSER uses a service-oriented architecture. Any component that is plugged into the Framework has access to the COMPOSER services. The COMPOSER suite of components is viewed as a collection of services that interact via well-defined extensible markup language encoded messages. An information router delivers messages to all interested consumers.

An examination of the COMPOSER requirements and the software engineering requirements points to the common integration pattern *observer*. This establishes a set of interested subscribers of a particular publisher's periodical. Only this set of subscribers receives an update. The subscribers can end their subscriptions at anytime, while candidate subscribers can request to be added to the set of subscribers of a particular publisher. A broker is responsible for maintaining publishers (i.e., services) and consumers. Whenever a data publisher informs the broker of an update, the broker updates the subscribers. Only the broker can directly interact with the constituent components of COMPOSER. Incoming state changes/data events appear as only an informational message, from a subscriber's perspective.

The COMPOSER NV (Figure 3) contains the user interface for COMPOSER. It displays network configuration and performance information intuitively and interactively. The entities displayed include force units such as dismounted, tracked vehicles, UAVs, UGVs, aircraft, satellites, and logistic supplies, which may be aggregated into groups, brigades, battalions, or various echelons. The entity behaviors are driven from the CES or the actual network. LM ATL's Vehicle-Platform-Terrain (VPT) model viewer library brings realistic mission-level aspects to the NV. The NV includes a two-dimensional and three-dimensional visualization of the battlefield with RF-link communications with line of sight point-to-point animation as an overlay. Vehicles move throughout the space, while viewed from multiple arbitrary viewpoints.

The NP accepts the communication requirements, including the number and types of platforms and nodes, their designations and trajectories, and generates a candidate communications plan. The traffic requirements are ex pressed as Information Exchange Requirements (IERs) that describe the periodicity, quantity, and priority of communications between specific nodes, or classes of nodes,

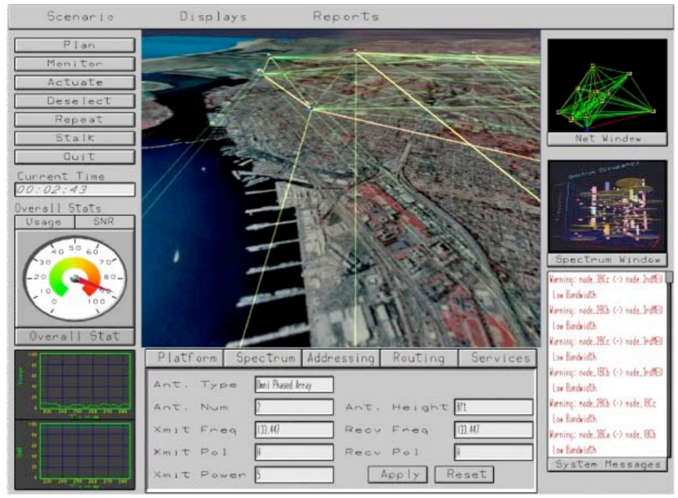

Figure 3. Prototype COMPOSER NV. NV provides multiple views (2D and 3D) including various performance metrics for both network planning and network monitoring tasks

during specified time intervals. The IERs may express additional information, such as protocols, packet sizes, and traffic statistics. The node movements are described as waypoints versus time. NP functions include the assignment or selection of node addresses, routing rules or tables as well as physical layer attributes such as power levels and frequencies or hop-sets. The NP can also actuate (i.e. distribute the plan to the network) communication plans. Provisions exist to import or monitor information from live networks for rapid response and continual communications maintenance.

The CES assesses candidate communication plans, as supplied by the NP. If mission requirements cannot be satisfied with the available resources, the NP in conjunction with the CES, provides suggestions to help the planner modify the plan, e.g., by reconfiguring resources at specific locations and mission times. Because the exact node positions and traffic distributions over time for future missions cannot be known precisely and because many mission evaluations of networks must be performed well before deployment, the COMPOSER CES falls into a distinctly different category than traditional network simulators.

Traditional network simulators are adequate for assessing detailed link protocols or high-fidelity modeling of moderately sized networks; COMPOSER is not designing link protocols, nor does it have precise information appropriate for high-fidelity modeling, yet the CES must evaluate aggregate performance of large networks much faster than real time (FTRT). For example, to plan a network a few hours before a multi-hour mission, the CES must evaluate the mission in minutes or less. Some mission scenarios may span days, weeks, or months. Iterative planning re-

quires many assessments in a short time. LM ATL has developed an efficient simulation tool CSIM [1] that performs FTRT modeling and visualizing of large complex systems. CSIM uses multiple levels of abstraction to simulate communication effects like terrain and weather as well as network effects like routing and quality of service (QoS), in a highly efficient manner. LM ATL is developing the COMPOSER CES based on CSIM technology. The CES provides the planner a rapid war-game capability to perform "what if" analyses, sensitivity studies, fault tolerance analyses, and other important functions that increase the robustness of the network plan. COMPOSER's CES is required to provide 60x faster than real time simulation with an average of no less than 4000 nodes and have the ability to dynamically create/delete units.

Preliminary benchmarks of the COMPOSER (Table 1) CES demonstrate a viable approach: 55 times faster than real time (one week in three hours) for 347 nodes communicating 32,000 types of IERs. This is over 7,000 real-time seconds in three hours. These results were obtained without tuning the simulation. Additional speedup is expected using abstraction techniques, including those described in the next section. The IERs were taken from the Caspian Sea scenario used on the WIN-T program. The IERs contain a variety of traffic, including voice, web-based, imagery, streaming video, video teleconferencing and other data, which is representative of an actual military scenario.

Table 1. Preliminary Benchmarks for CES. initial results without tuning, but uses actual IER traffic from the Caspian Sea Scenario

Nodes	Unique IERs	Times Real Time
341	31,468	55X
682	62,816	22X
1023	94,224	12X

COMMUNICATIONS EFFECTS SIMULATOR (CES) DETAILED DESCRIPTION

The heart of COMPOSER CP architecture is the CES (Figure 4) that leverages the developments of LM ATL's discrete event simulator CSIM to model dynamic OTM network architectures at multiple abstraction levels for user selectable efficiency and accuracy. The COMPOSER is extending CSIM's existing radio and network effects library by extracting behaviors from the team's existing detailed models and from their simulation results, including TIREM [2] developed by Alion, a standard used extensively by DoD to predict terrain based propagation loss.

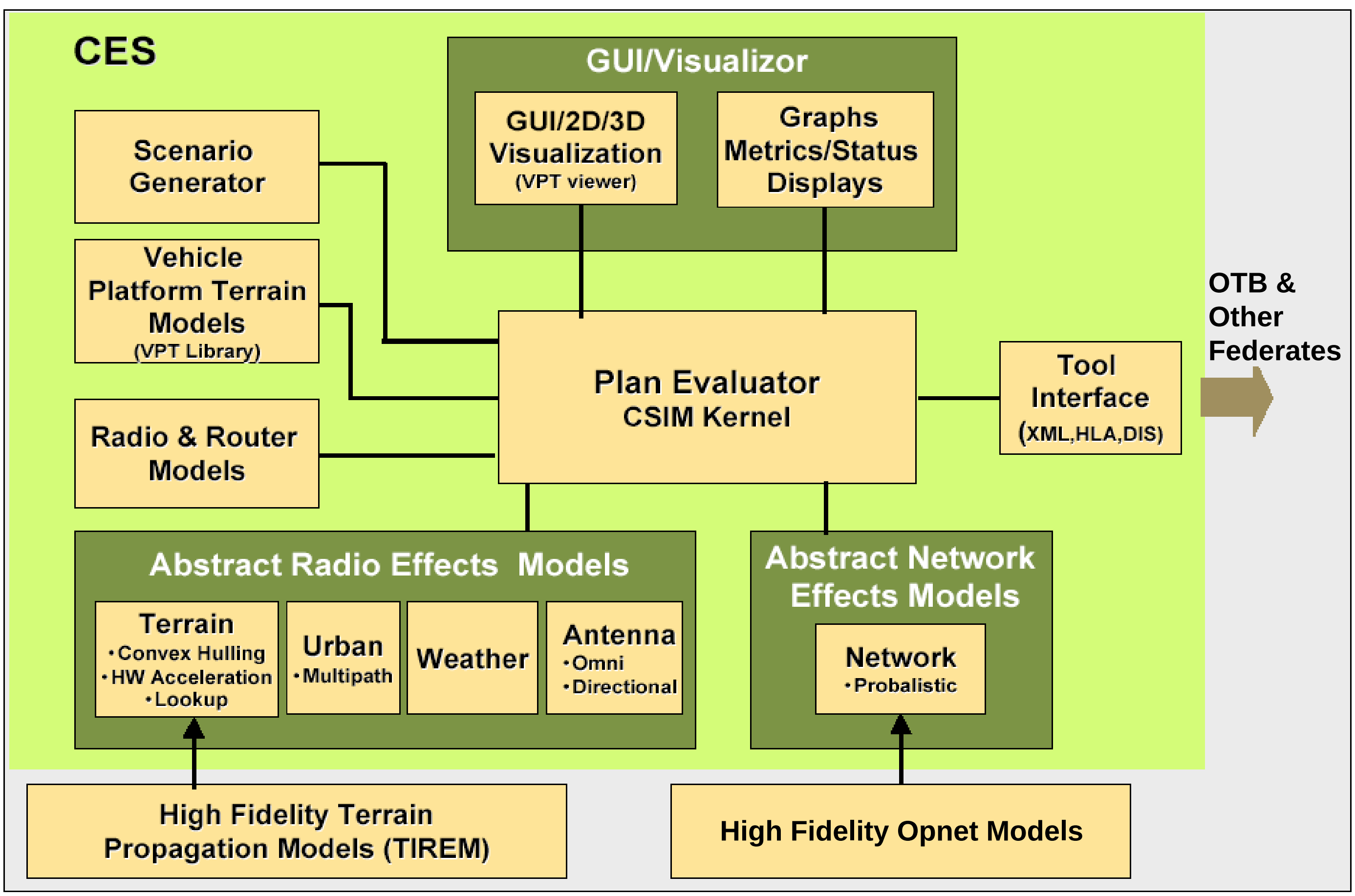

Figure 4. Detailed COMPOSER Communications Effects Simulator (CES) Architecture

LM ATL pioneered and demonstrated techniques for abstracting network models on the CECOM Virtual Network Simulator (VNS) [3] and other government [4] projects, while maintaining accuracy and gaining multiple orders of magnitude in speed. The efficiency of CSIM enables rapid evaluation of communication plans and evaluates the sensitivity of candidate plans with unanticipated variations.

The CSIM model library contains wireless models that can selectively model various aspects of networks and links at multiple levels of abstraction for speed efficiency and with sufficient accuracy. CSIM's wireless models are constructed in a layered approach. The models can focus on physical effects, such as propagation, channel access and interferences. They can focus on the higher-level protocols, such as the network and routing layers or they can resolve all layers simultaneously. The base models are generic and can be parameterized or configured to exhibit characteristics of specific wireless systems. Additionally, several configured models of specific systems are included in the library, such as: several variants of 802.11, SINCGARS, EPLRS, Ad hoc Routing, AODV, Link state routing, IP based routing and protocol, satellite links, directional antennas and networks. The physical layer models resolve frequency, interference, modulation and power. The propagation functions include: Rayleigh Fading, Longley-Rice Irregular Terrain Model (ITM), Okumura Hata, Jake's Model, various free-space, and R^ϒ models.

Abstraction of the radio effects is essential to achieve FTRT simulation. The calculations to predict the propagation of RF waves due to terrain, such as the Longley-Rice model, are time consuming, especially when performed repeatedly. The Longley-Rice model accounts for terrain height but not surface factors, such as vegetation, buildings, and surface materials such as soil or water permeability, reflectance, or absorption. New attenuation values are needed iteratively during simulations as radios move or change frequencies.

The attenuation calculations are time consuming because a two-dimensional integration must be performed between each transmitter-receiver pair (A and B) to account for the terrain elevations at all points between A-B which may obstruct or partially weaken the signal. The path's width depends on the bandwidth of the signal, and generally spans within some small angle around B as seen from A, and vice-versa. The primary field of influence between A and B produces a convex hull due to wave-spreading with distance. The degree to which complex hull is truncated or obstructed by the terrain determines the amount of attenuation between A and B. A 3-D computation must be performed for each of thousands of intervening points for each propagation calculation.

One approach to accelerate the repeated access of propagation-attenuation values during simulations is to pre-calculate the values once, for a relatively coarse grid, store the values in a table, and retrieve and interpolate them during simulations. However, the dimensions of this database can produce a database of impractical size that would hinder access times due to swapping/caching inefficiencies and disk seek latencies. The dimensions would be roughly (N^4)/2, where N is the number of grid points along an edge of the space. A sub-table of (N-1) x (N-1) entries is needed at each grid point to specify the attenuation to each of the other grid points, and one of these sub-tables is needed at each of the NxN grid points. Assuming symmetry, the total table can be reduced by a factor of 2. So the "rectangular" structure would be (N-1) x (N-1) xNxN/2. If attenuation values were recorded as a single byte in dB, then a 50x50 Km grid with 50m spacing between points (N=1000) would require 0.5 Terabytes of storage (500 GB). A preferred method would consume only an order of a few 100's of Mbytes. The nature of radio attenuation causes the above method to waste much space storing fine data at long ranges, forcing overly coarse grids at short ranges. COMPOSER is developing a new rectangular method based on a log-polar storage compression technique, which addresses the accuracy and efficiency issues.

The COMPOSER Log-Polar terrain propagation technique stores pre-calculated, or measured, attenuation values as a series of concentric rings around each grid-point. Each attenuation value can be stored as a single-byte in dB over a 100-dB range with 0.4 dB resolution. A random Rayleigh fading function is applied to the model multi-path, scattering and diminishes the need for more resolution. An Rϒ, where R is range and ϒ ranges from 2 to 4 is superimposed to match the natural dynamic range with distance profile and to provide smoother interpolation between grid-points. Each ring is divided into angular segments, such as Na=20, so that an attenuation value can be placed at each angle-intersection of the ring. 20 segments provide maximum angular error of only 9-degrees, enough for typical radio directionality. A number of rings, Nr, are spaced logarithmically outward from the given grid point. For example, seven rings are spaced at Km distances of 0.4, 0.8, 1.6, 3.2, 6.4, 12.8, and 25.6. Distances between and beyond can be interpolated by accessing the nearest points. Points near sharp terrain gradients can be given higher resolution sections.

Our Log-Polar technique requires K x N x N bytes, where K = Na x Nr. Assuming the above grid parameters, then each grid point requires 7x20 bytes, and a 50x50 Km grid with 50m spacing between points (N=1000) requires only 140 MB. This is a reduction of 500/0.14 or 3,571:1 over the "Rectangular" method above. Each propagation lookup requires accessing four points (two from each side A/B to

interpolate). This provides a massive speed-up over the integration methods (Figure 5).

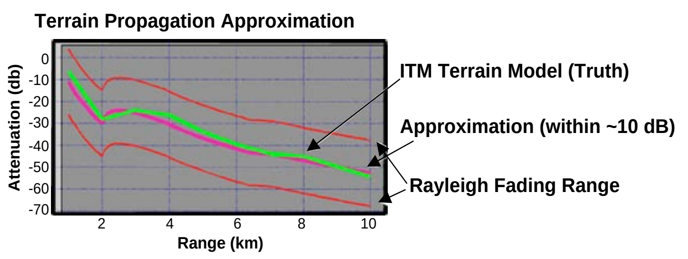

Figure 5. Log-Polar Method Developed and Tested. Preliminary results showing 10x speedup over Longley-Rice ITM with <5% error. Reasonable memory footprint, ~100MB for 2,500 km^2 area at 30 m resolution. Development and optimization continuing

In addition to the Log-Polar technique for modeling propagation, the COMPOSER team is developing and applying several additional methods to realize suitably efficient, sufficiently predictive link assessments including:

- Incorporation of convex hulling techniques to speed calculations for longer paths.
- Simplification of internal TIREM calculations given knowledge gained by analyzing the digital terrain itself ahead of model execution.

Development of predictive techniques to handle entity movement within the CES as static answers, rather than as a series of separate link calculations.

SUMMARY AND CONCLUSION

Each LM ATL team member has continuing internal and government contract investments that are supportive of the developments being addressed under COMPOSER. These future investments allow the team to iteratively develop and validate our CP architecture to ensure a smooth transition from the proof of concept demonstration to a Technology Readiness Level (TRL) 6 or higher tool over the course of the four-year program with minimum risk.

This paper has described the key technical aspects of the program. The overall concept of operation and architecture were presented. The COMPOSER CP is comprised of a NP, CES and NV and an open pluggable Framework allowing the components to work together and enabling extensibility. Our CP approach supports both pre-deployment OTM network planning and dynamic in-the-field replanning. The CP receives a detailed mission plan that contains available resources (equipment, radios, policy, etc.), maneuver plans, and the associated terrain information describing planned movements and mission communications requirements. It generates a communications plan and validates it using FTRT simulation.

The central component of COMPOSER is the CES that is using LM ATL's CSIM simulation tool to provide FTRT simulation of the communications plan under the specified scenarios. This paper describes the CES operation and architecture in detail. CSIM's ability to simulate at multiple levels of abstraction is the key to simultaneously providing both speed and accuracy. As described, abstraction of both network and radio effects are being developed and used by COMPOSER to accelerate CES operations. Preliminary performance results of the CES were presented. Several key abstraction techniques were presented in this paper. Additional extensions and refinements to these and other techniques will evolve with COMPOSER. This technology will ensure the success of COMPOSER as it fills a critical gap in OTM simulation based communications planning for present and emerging military networks.

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